Ground-Check Corrections in Radiosonde Data on the R/V Mirai During Nauru99

J. Wang, W.O.J. Brown, D. J. Carlson, H. L. Cole, E. R. Miller, and D. B. Parsons
National Center for Atmospheric Research
Atmospheric Technology Division
Boulder, Colorado

K. Yoneyman
Japan Marine Science and Technology Center
Yokosuka, Japan

Introduction

The ground-check (GC) correction for Vaisala radiosonde measurements is an on-site calibration in temperature (T), relative humidity (RH), and pressure (P) prior to launch based on radiosonde measurements at reference values. GC corrections are applied to the entire radiosonde profile although the procedure provides calibrations at only certain reference values. The standard Vaisala GC set was used during the Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) and at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site. A different humidity calibration device VAPORPAK H-31 manufactured by Digilog Instrument (Horn 1993) was used to calibrate temperature and humidity on the research vessel (R/V) Mirai during Nauru99. GC corrections are designed to remove possible biases and/or errors of radiosonde instruments before launch. However, human errors, contamination, and degradation of GC instruments with ages and other factors can introduce errors in GC corrections (Kostamo 1989; Lesht 1995). As a result, GC corrections do not improve the measurement accuracy, and are likely in some cases to reduce it. In this paper, we will show errors in RH_GC corrections from Nauru99, TOGA-COARE, and ARM's SGP radiosonde data, investigate causes for those errors, and suggest approaches to correct them.

A dry bias has been found in the Vaisala radiosonde RH measurements during TOGA-COARE (Zipser and Johnson 1998). Such dry bias is due to contamination of the polymer used as the dielectric material in the capacitive RH sensor (humicap). The National Center for Atmospheric Research/Atmospheric Technology Division (NCAR/ATD) has been collaborating with Vaisala to correct the dry bias for both A-type and H-type humidity sensors (Miller et al. 1999). In August 1998, Vaisala introduced a new desiccant material in the radiosonde package that is expected to reduce the contamination by approximately 30% to 50%. Radiosondes with this new desiccant were used on the R/V Mirai during Nauru99, and will be evaluated for the dry bias in this paper by examining several humidity parameters and comparing precipitable water vapor (PWV) calculated from radiosonde data with that measured by a microwave radiometer (MWR).

Instruments and Data

Nauru99 was one of ARM's field projects to study tropical climate in the vicinity of Nauru in the Tropical Western Pacific (TWP) during the summer of 1999 from June 16 through July 15, 1999. Two research ships participated in Nauru99: the National Oceanic and Atmospheric Administration (NOAA) R/V Ronald H. Brown and the R/V Mirai from the Japan Marine Science and Technology Center (JAMSTEC). Vaisala RS80-H radiosondes were released every three hours on the R/V Mirai from June 20 to July 5, 1999. The VAPORPAK H-31 was used to calibrate temperature and humidity before launching radiosondes. The instrument has a RH polymer-based servo-controlled humidity chamber and can generate humidity in the range of 5% to 95% RH reliably, with a 0.2% RH stability and a maximum error of 1.5% RH (Horn 1993). The VAPORPAK reference RH was set at 70% on the R/V Mirai, which is more representative of the tropical environment than 0% RH reference value used in the Vaisala GC set. A MWR manufactured by Radiometrics Corporation was operated on the R/V Mirai to measure PWV and integrated liquid water. The PWV is also calculated from radiosonde data and compared with that from the MWR.

More than 8,000 Vaisala RS80 radiosondes (both A and H types) were launched at 30 of the 42 radiosonde stations in the TWP during TOGA-COARE (from November 1992 to February 1993). The Vaisala GC instrument was employed at some sites. The GC set consists of a small, O-ring-sealed, desiccant-filled aluminum chamber that is fitted with a certified mercury thermometer. The chamber provides a 0% RH environment of ambient temperature against which the radiosonde output can be checked. Normal procedure is for the operator to insert the radiosonde into the GC set, wait until the sounding software indicates that the system has achieved equilibrium, and read the temperature from the mercury thermometer. The reference data (i.e., the thermometer reading and assumed 0% RH) are entered into the processing computer, which automatically reads the corresponding radiosonde information. In this study, we analyze the radiosonde data at four island sites (Misima, Thursday Island, Darwin, and Gove) and two ships (R/V Hakuho Maru and R/V Vickers), where GC corrections were performed and the GC data are available.

We also analyze the GC data collected at the central facility (CF) of the ARM's SGP site between July 1993 and May 1994. The Vaisala GC instrument was used at the CF. The ground checks were terminated at the SGP site in August 1994 after the procedural artifacts were found in T_GC corrections (Lesht 1995).

Characteristics of GC Corrections

The following section discusses GC corrections during Nauru99, TOGA-COARE, and two intensive operational periods (IOPs) at the SGP site.

On the R/V Mirai during Nauru 99

The time series of GC corrections for RH and T are shown in Figure 1. RH_GC ranges from -6% to 4% with a mean of 0.05% and a standard deviation of 1.83%. 40% of the cases have magnitudes larger than

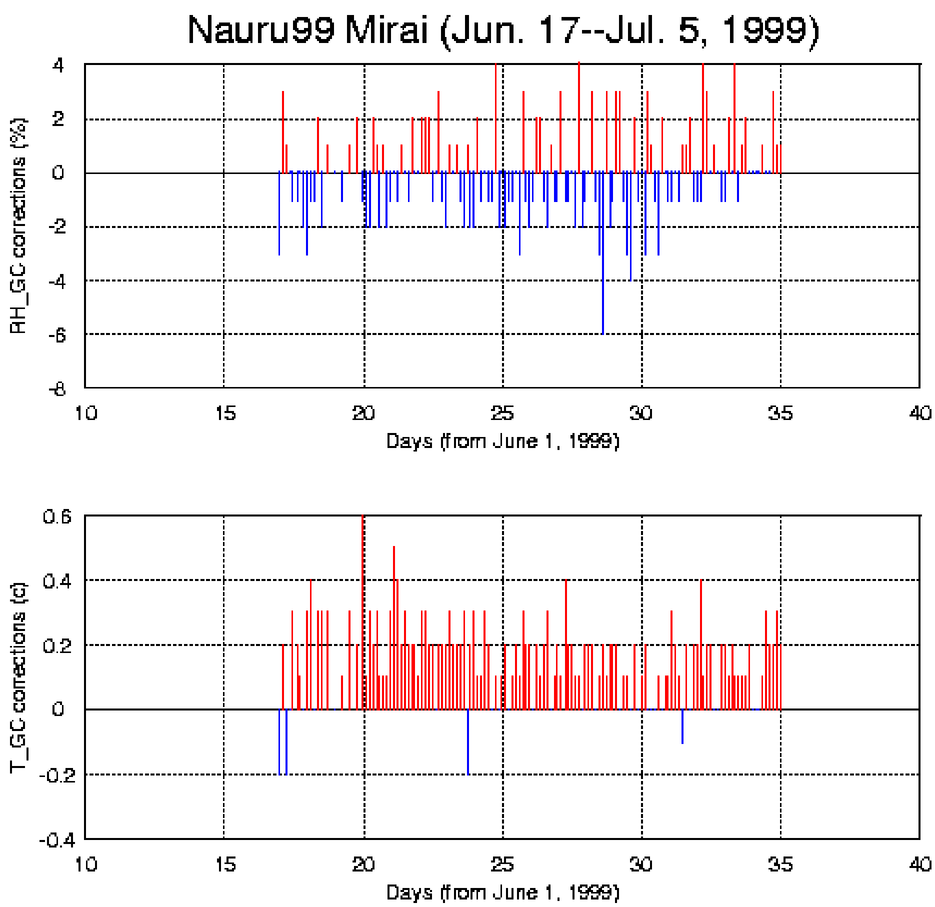

Figure 1. Time series of GC corrections for RH and T on the R/V Mirai during Nauru99.

the manufacturers' specifications for the accuracy of RS80-H radiosondes (±2%). Note that radiosondes do not always behave as well as advertised, so the errors imparted by the GC are possibly smaller than the errors from other sources. RH_GC shows unexpected diurnal variations (Figure 2), corresponding to shifts of four personnel (person A working at 21 Greenwich mean time (GMT) and 00 GMT, B at 3 GMT, 6 GMT, and 9 GMT, C at 12 GMT and 15 GMT, and D at 18 GMT). Several factors can result in this human-dependent trend. First, not keeping the radiosonde inside the chamber for a long enough time could make the VAPORPAK H-31 unable to stabilize at 70% RH and/or make the radiosonde not reach equilibrium, but 70% RH reference was still entered into the radiosonde software system. It takes several minutes for the VAPORPAK H-31 to respond to a 1% RH stability level. Second, the chamber could be contaminated by outside air because the operator did not insert the radiosonde into the chamber quickly or deeply enough. Third, the operator mistyped the reference RH into the system. The consistent colder radiosonde temperatures displayed in T_GC throughout the observational period (Figure 1) is possibly due to the fact that the radiosondes were stored in an air-conditioned room although GC was conducted in a well-ventilated launching room.

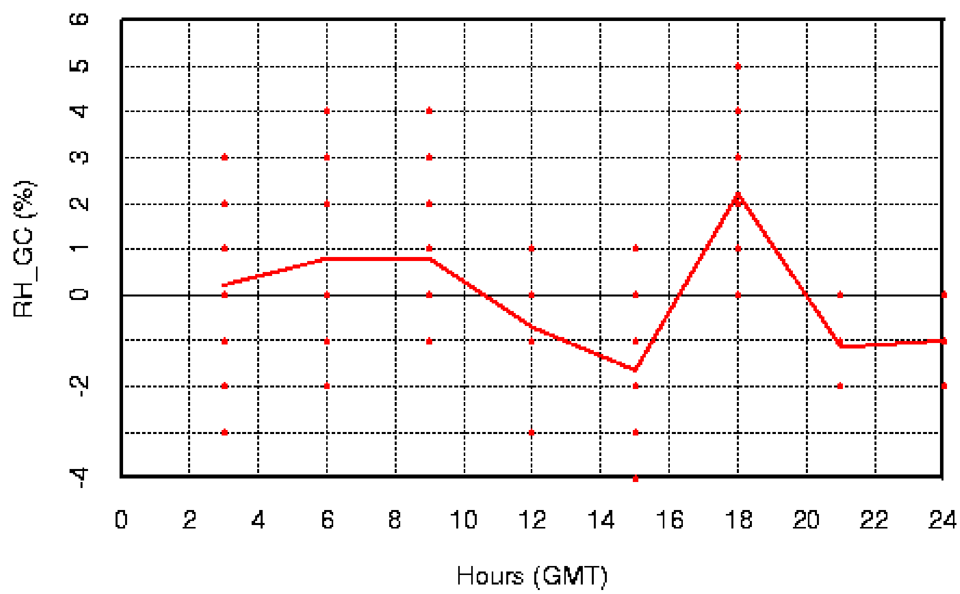

Figure 2. Diurnal variation of RH_GC corrections. Dots represent individual observations. The solid line shows averages of all points at each observation time.

During TOGA-COARE

The histograms of RH_GC corrections during TOGA-COARE show moist biases in the Vaisala humidity sensor at Dawin, Misima, and Thursday Island for 59%, 50%, and 34% of all radiosondes, respectively (Figure 3). However, radiosondes used at Gove and Vickers had dry biases with a mean of 1.23% and 2.09%, respectively (Figure 3). Experts at Vaisala anticipated that RH_GC corrections would be positive with a distribution similar to that at Gove and Vickers, representing the humidity sensor's dry bias due to contamination and normal aging (personal communication with Ari Paukkumen 1999). The soundings at Vickers show very small dry bias, suggesting that the GC corrections can help removing the bias in the data in some cases. The possible explanation for the moist bias at Dawin, Misima, and Thursday Island is the old desiccant and human errors. In a moist environment, such as in the Tropics where TOGA-COARE was located, the reference RH value can be above 0% if the chamber containing desiccant is contaminated by moisture from outside, and/or the desiccant is deteriorated. However, the GC software still interprets the reference RH as 0%. Radiosonde-measured RH could also be above 0% if the operator does not allow the RH sensor to stay in the chamber for enough time to dry to 0%, and/or the old desiccant is incapable of drying the air inside the chamber to 0%. As a result, the RH_GC correction (reference-sonde) could be negative. The operator is responsible for inspecting the desiccant and changing it as soon as its color has changed from gray to blue. But this does not always happen because operators either do not notice the desiccant's color change or they are not familiar with the proper operating procedure. The time evolution of RH_GC corrections at Misima in Figure 4 shows the largest moist biases from January 19 to February 11 in 1993 and reasonable values suddenly afterwards. The RH GC correction changes form -6% at 10:49 GMT to 1% at 16:43 GMT on February 11, 1993. Radiosondes at those two times were manufactured at the same date and came from the same batch. The possible explanation is that the old desiccant was replaced on February 12, 1993.

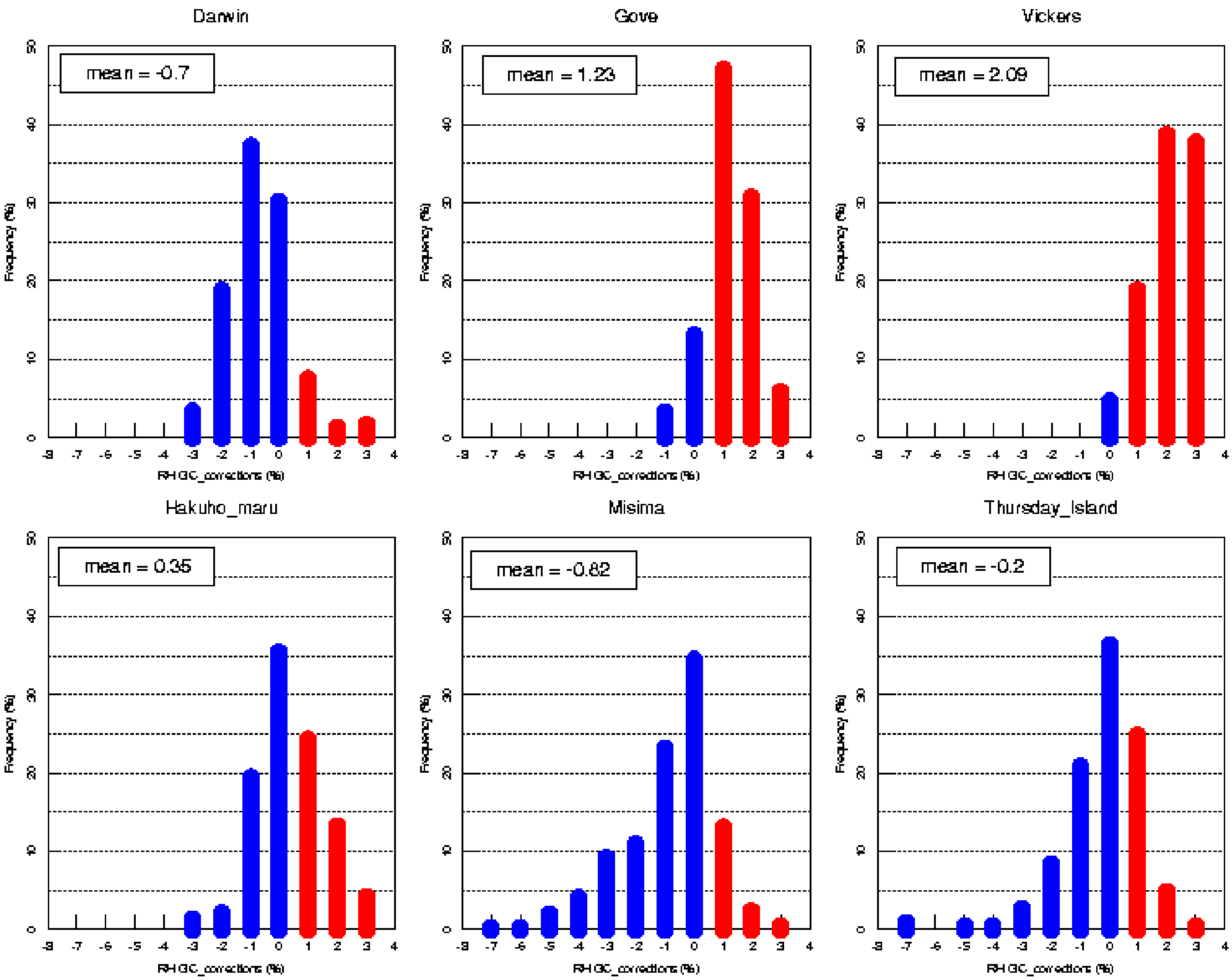

Figure 3. Frequency distributions of RH-GC corrections at Darwin, Gove, R/V Vickers, R/V Hakuho_maru, Misima, and Thursday Island derived from four-month (November 1992 to February 1993) radiosonde data. The mean value at each station is also given in the plot.

The T_GC corrections at six stations during TOGA-COARE consistently show that the radiosonde reports higher (warmer) temperature than the reference thermometer with a mean of -0.14°C to -0.44° C (not shown here). This warm bias could be attributed to two factors: a not-well-ventilated shelter where the GC is conducted, and a failure of the GC set to be in thermal equilibrium.

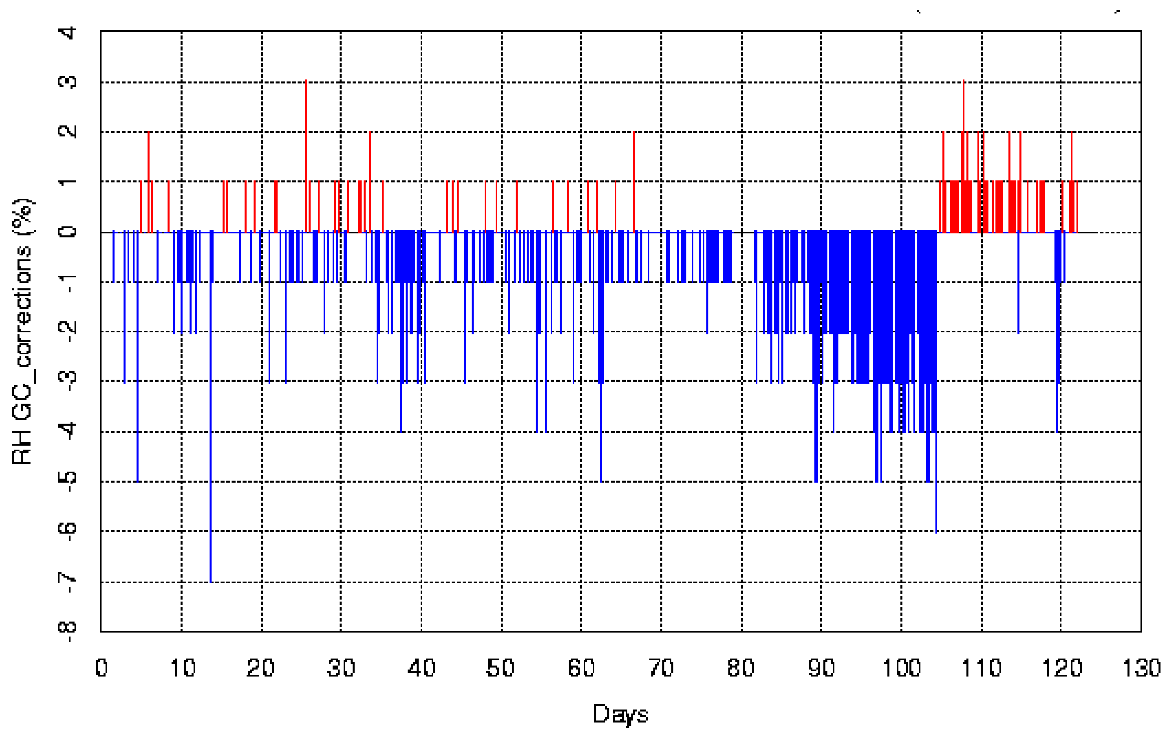

Figure 4. Time series of RH_GC corrections at Misima from November 1, 1992, to February 28, 1993.

At the CF of ARM's SGP Site

Time series of GC corrections in RH, T, and P show larger magnitudes and stronger variations in all three parameters during two IOPs (January and April-May of 1994) (Figure 5). The variability is associated with the involvement of more personnel during IOPs when 24-hr operations require different personnel to prepare and launch radiosondes (Lesht 1995). The warm bias shown in T_GC corrections is consistent with that during TOGA-COARE. As suggested by Lesht (1995), this warm bias is likely resulting from a failure of the GC set to be in thermal equilibrium when the GC is conducted inside a heated shelter.

Evaluation of Dry Bias on the R/V Mirai during Nauru99

Several different methods have been utilized at NCAR/ATD to detect Vaisala radiosonde humidity biases during TOGA-COARE. These techniques include comparisons between surface mixing ratio (MR) from an independent surface instrument and the averaged MR in the mixing layer from radiosonde data, histograms of convective available potential energy (CAPE) and relative humidity, and examination of Skew-T plots to look for saturation within cloud layers (see Figure 6). For the Mirai radiosonde data, differences between the surface and mixing layer MR have a mean of 0.86 g/kg and are larger than 2 g/kg for only 7 of 139 soundings. This is within the limit of 1 g/kg to 1.25 g/kg predicted by the Monin-Obukhov similarity theory for a well-mixed tropical maritime boundary layer. For soundings from TOGA_COARE that have dry biases, differences of 2 g/kg to 3 g/kg were commonly

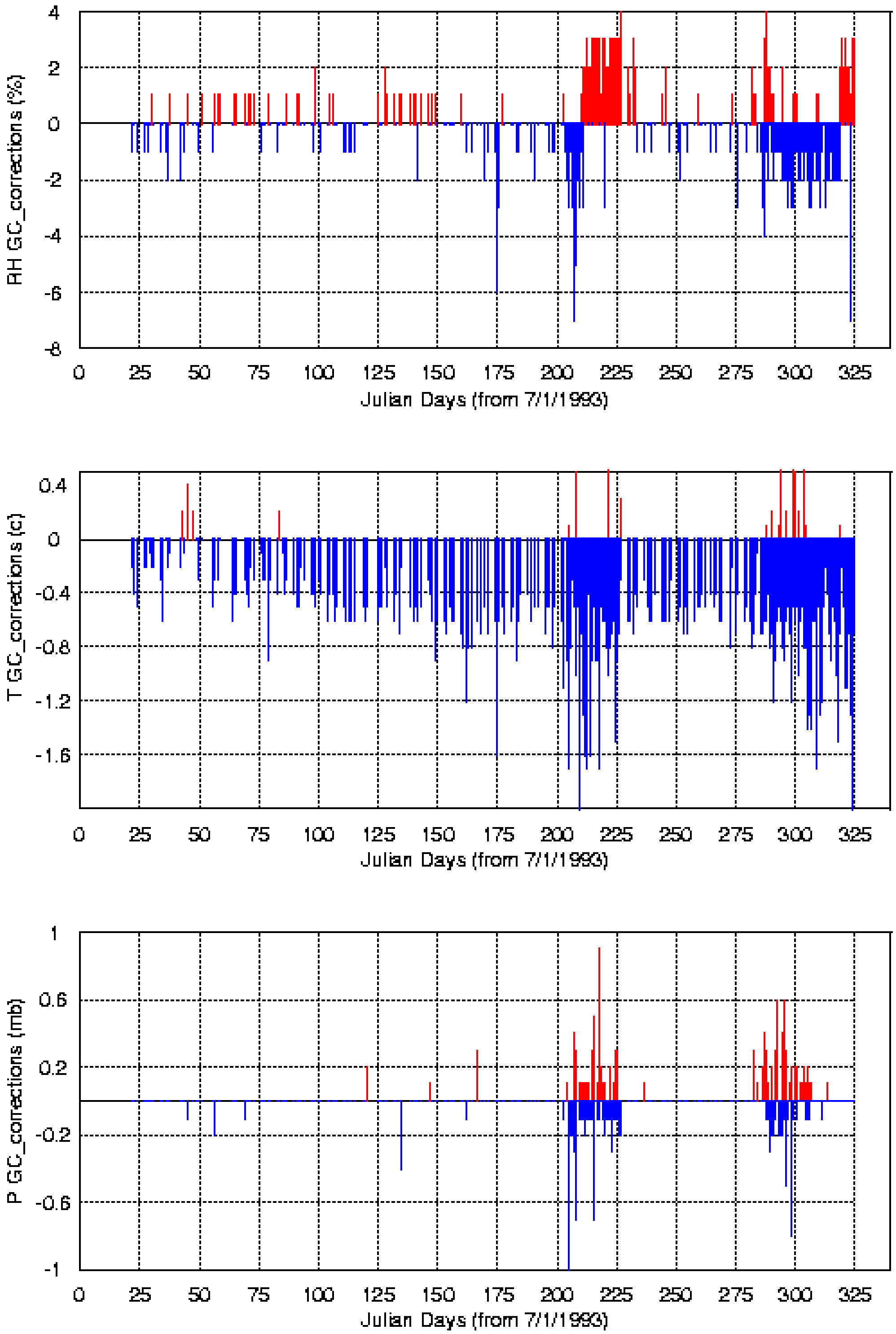

Figure 5. Time series of GC corrections for RH, T, and P at the CF from July 1993 to May 1994.

observed. The histogram of RHs shows occurrences of RHs above 96%, which were not present during TOGA-COARE. There are 56% of the soundings with CAPE values larger than 800 J/kg, which is considered as a threshold for convection initiation (LeMone et al. 1998). The visual examination of Skew-T plots of all soundings indicates penetrations of cloud layers in some soundings characterized by nearly moist adiabatic conditions, and paralleling and overlaying of the dew-point temperature trace on the temperature trace. As an example, the Skew-T plot for June 27, 1999, shows saturation in a thick cloud layer from 800 mb to 600 mb, which corresponds well with the cloud layer detected by the profiler radar (Brown et al. 2000). These techniques shown in Figure 6 suggest that there is no evidence of the detectable dry bias for radiosondes packaged with the new desiccant. The new desiccant reduces the dry bias contamination by 30% to 50%. Radiosondes used on the R/V Mirai were less than three months old and thus have a very small dry bias contamination (on the order of 2%).

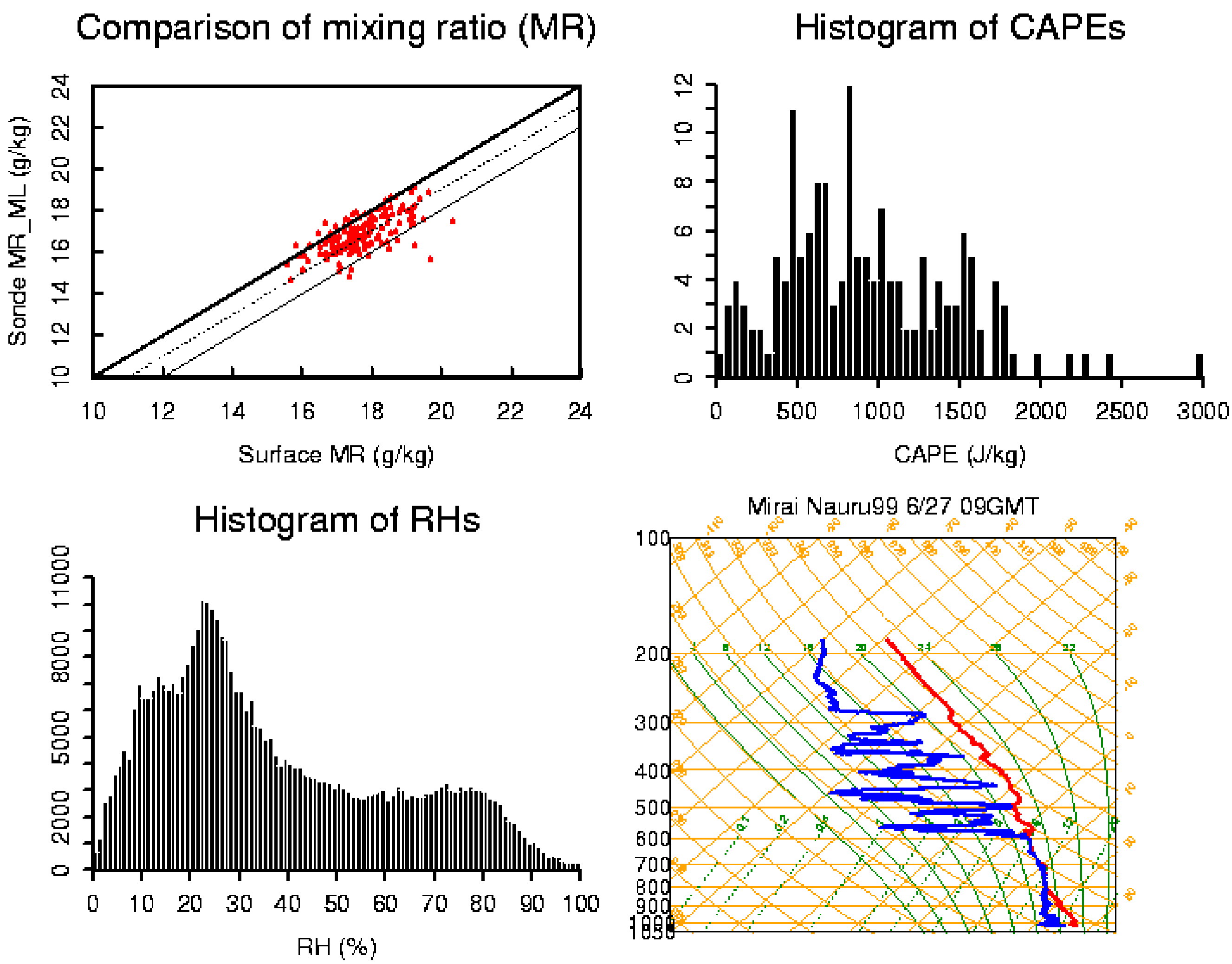

Figure 6. Scatter plot of surface MR versus radiosonde_measured mean mixing-layer MR and histograms of CAPEs and RHs are shown here, and are derived from 139 soundings collected on the R/V Mirai during Nauru99. Skew-T plot of sounding at 09 GMT on June 27, 1999, is also shown.

Comparison of PWV with MWR on the R/V Mirai during Nauru99

Radiosonde-measured PWV has a good agreement with that measured by the MWR with a correlation coefficient of 0.91 and a mean difference of 0.02 ± 0.22 cm (Figure 7). This reinforces the conclusion drawn above that there is no detectable dry bias in the radiosonde data. However, the radiosonde data shows more variations, especially on a diurnal time scale. The difference in PWV between the radiosonde and the MWR is partially attributed to RH_GC corrections applied to the radiosonde data. The diurnal variation of PWV difference is very similar to that of RH_GC corrections shown in Figure 2. The temporal variation of RH_GC corrections explains 25% of the variability in PWV difference (a correlation coefficient of 0.51) (Figure 8). Removing the RH_GC corrections in the radiosonde humidity data improves the comparison of PWV (Figure 7). The correlation coefficient between the two is 0.93. And only 5 out of 139 soundings had PWVs that differed from the MWR PWVs by more than 2 mm. This comparison again implies that RH_GC corrections introduce errors in the radiosonde humidity measurement instead of improving its accuracy, as expected.

Conclusions

While the radiosonde GC procedures are designed to reduce errors in radiosonde measurements, we have presented several examples where the procedure itself introduces errors of ~1% to 6% in RH and 0.2°C to 1.8°C in T. More importantly, it can introduce artificial temporal and spatial variations, such as unexpected diurnal variation in RH on the R/V Mirai, day-to-day variations at Misima during TOGA-COARE and at the CF, and spatial variations during TOGA-COARE as a result of variations of RH_GC

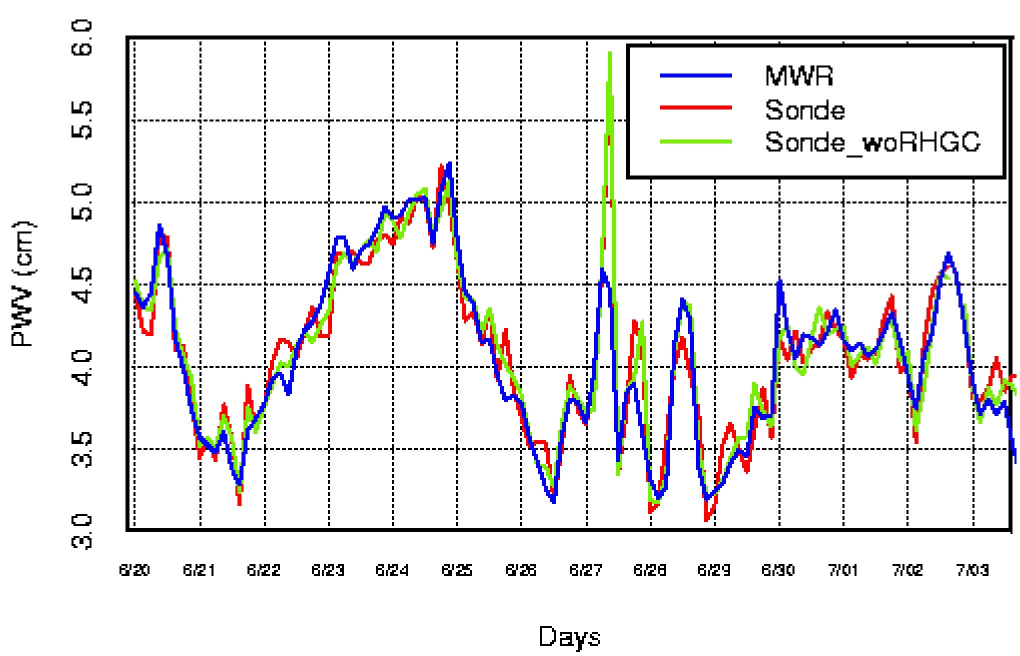

Figure 7. Comparison of PWV from MWR and radiosonde data with and without RH_GC corrections on the R/V Mirai during Nauru99.

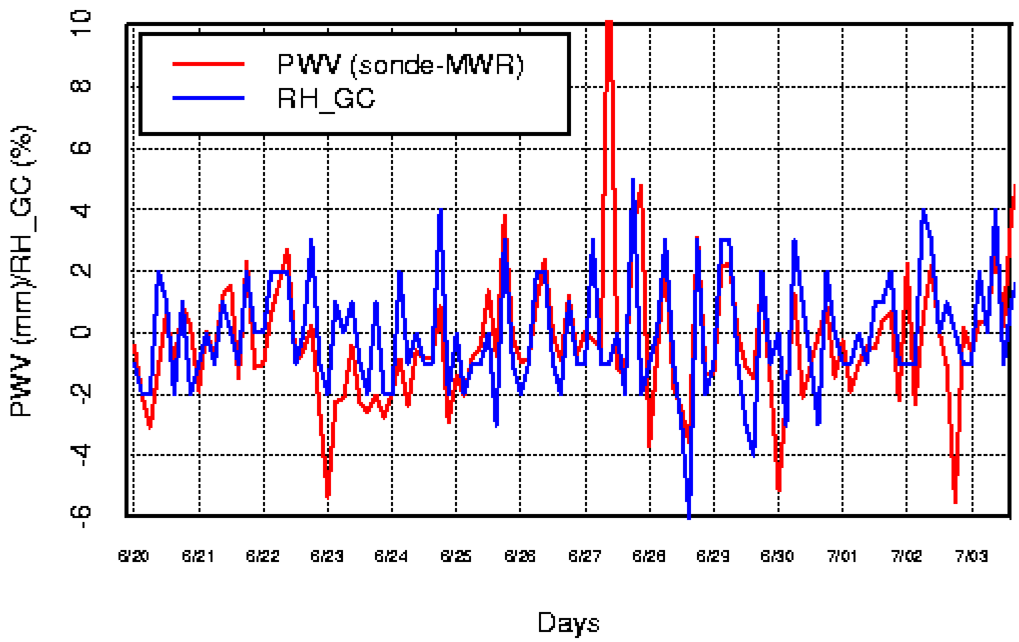

Figure 8. Time series of RH_GC corrections and PWV difference (sonde-MWR) on the R/V Mirai during Nauru99.

corrections among stations. On a global scale, the inconsistency in application of GC corrections at radiosonde stations around the globe affects spatial and temporal variations of humidity and temperature derived from radiosonde data. Errors in RH_GC corrections are due to the variable experience of the personnel, incorrect usage of GC instruments, contamination of GC by the surrounding environment, and improper function of GC parts such as the desiccant in the Vaisala GC set. It should be mentioned that if the GC has been done correctly, it would help reducing the errors/biases in the radiosonde data from other sources. For instance, the GC at Vickers helps removing the dry bias. Based on this study, it is recommended that the GC corrections be removed from radiosonde data with GC information recorded if errors/biases are found in the GC data. For most operational purposes, the GC data should be stored but not applied to the data before it is included in the real-time operational analysis. The GC data should be archived in case errors are detected in the sonde data set, such as our experience with the dry bias, as it may provide some guidance on how to correct the data. For research purposes, the GC will likely impart additional errors to the sounding data set. For this reason, the decision of whether to use the data with or without the GC should be established on a case-by-case basis after careful examination of the GC and sonde data sets. The additional accuracy in radiosonde data required for many research applications requires that some additional calibration and correction procedures should be applied, such as calibrating the radiosonde data using MWR data in ARM. The GC correction has been terminated at the CF for ARM's SGP site since August 1995, but was continuously employed in some field experiments such as on the R/V Mirai during Nauru99. The termination of the GC correction is not only due to discovered errors in the GC data, but also in favor of scaling the sonde humidity data with MWR measurements. We suggest that a consistent guideline for radiosonde GC correction should be made for all sites and all field experiments within the ARM Program.

For the first time, the accuracy of radiosondes packaged with the new desiccant has been tested using radiosonde data collected on the R/V Mirai during Nauru99. By using several different techniques for detecting RH biases in the tropics and also comparing with MWR data, we found no detectable dry bias for radiosondes used on the R/V Mirai that were less than 3 months old. A new type of protective shield on the sensor boom for RS80 radiosondes was introduced in May 2000 and is expected to remove the dry bias completely (personal communication with Ari Paukkumen at Vaisala).

References

Brown, W., D. Parsons, E. Miller, and S. Cohn, 2000: Profiler, radiometer, SST and Met Obs from the R/V Mirai during Nauru99. This proceedings.

Horn, R. D., 1993: A high-performance RH generation system. *Sensors*, **10**, 89-99.

Kostamo, P. J., 1989: RS 80 radiosonde ground check corrections of temperature. *Vaisala News***,** **117-118/89**, 3-7.

LeMone, M., E. J. Zipser, and S. Trier, 1998: The role of environmental shear and thermodynamics conditions in determining the structure and evolution of mesoscale convective systems during TOGA-COARE. *J. Atmos. Sci.*, **55**, 3493-3518.

Lesht, B. M., 1995: An evaluation of ARM radiosonde operational performance. In: *Proceedings of Ninth Symposium on Meteorological Observations and Instrumentation*, March 27-31, 1995, Charlotte, North Carolina, American Meteorological Society, pp. 6-10.

Miller, E., J. Wang, and H. L. Cole, 1999: Correction for dry bias in Vaisala radiosonde RH data. In *Proceedings of the Ninth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9903/miller-er-99.pdf

Zipser, E. J., and R. H. Johnson, 1998: Systematic errors in radiosonde humidities a global problem? *Tenth Symposium on Meteorological Observations and Instrumentation,* January 11-16, 1998, Phoenix, Arizona, American Meteorological Society, pp. 72-73.